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CODE OF SAFETY FOR HANDLING CRYOGENIC LIQUIDS

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Indian Standard
CODE OF SAFETY FOR HANDLING CRYOGENIC LIQUIDS

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Indian Standard

CODE OF SAFETY FOR HANDLING CRYOGENIC LIQUIDS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 10 August 1970, after the draft finalized by the Chemical Hazards Sectional Committee had been approved by the Chemical Division Council.

0.2 Handling cryogenic liquids safely is largely a matter of knowing their properties and using suitable procedures based on that knowledge. There are a number of general precautions and safe practices which shall have to be observed because of extremely low temperatures and high rates of conversion into gas of all the liquids mentioned in this standard. There are also certain specific precautions which shall have to be followed where a particular liquid may react with contaminants or may present a hazard to life.

0.3 The user of any cryogenic liquid covered by this code should be familiar with both the general and specific precautions outlined in this Standard. He should also be thoroughly familiar with the instructions provided with any equipment to be used with the liquid.

0.3.1 Skilled personnel who are aware of the hazards of handling of cryogenic liquids may, under laboratory conditions, exercise some discretion in the interpretation of the recommendations. It shall have to be remembered, however, that people tend to learn by example, and what may be 'safe' practice in the hands of the skilled may be a hazard to the unskilled, particularly in this instance where the unsafe methods are the quickest and easiest.

0.4 For the purpose of easy reference, the code has been divided into three sections, namely (a) liquefied atmospheric gases whose boiling points are not very low, such as oxygen, nitrogen, argon, neon and krypton; (b) liquid helium which has a very low boiling point; and (c) liquid hydrogen which is highly flammable.

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1. SCOPE

1.1 This code recommends safe procedures for handling cryogenic liquids having boiling point below $-150^{\circ}C$, such as liquid oxygen, nitrogen, argon,

neon, krypton, helium and hydrogen. This standard, however, does not include recommendations for bulk handling of cryogenic liquids.

SECTION I LIQUEFIED ATMOSPHERIC GASES

2. PROPERTIES AND PHYSICAL CONSTANTS OF ATMOSPHERIC GASES

2.1 The important properties and physical constants of atmospheric gases are briefly described in Tables 1 and 2 respectively.

3. GENERAL SAFETY PRECAUTIONS

3.0 General — The potential hazards in handling liquid oxygen, nitrogen, argon, helium, neon and krypton stem mainly from two important properties they have in common, namely (a) they are extremely cold, and (b) very small amounts of liquid are converted into very large amounts of gas. The general precautions outlined hereunder are recommended for avoiding any potential injury or damage resulting from these two characteristics.

3.1 Handling

3.1.1 At their extremely low temperatures, cryogenic liquids always produce an effect on the skin similar to a burn. When spilled on a surface they tend to cover it completely and, therefore, cool a large area. The gases issuing from these liquids are also extremely cold and may produce burns. Delicate tissues, such as those of the eyes, may be damaged by an exposure to these cold gases which is too brief to affect the skin of the face or hands.

3.1.2 One should stand clear of boiling and splashing liquid and its issuing cold gas. Boiling and splashing always occur when charging a warm container or when inserting objects into the liquid. These operations shall be performed *SLOWLY* to minimize boiling and splashing.

3.1.3 Any unprotected part of the body should never be allowed to touch uninsulated pipes or vessels containing liquefied atmospheric gases; the extremely cold metal may stick fast and tear the flesh, if attempt is made to withdraw from it. Tongs shall be used to withdraw objects immersed in liquid. In addition to the hazard of burns or skin sticking to cold materials, objects that are soft and pliable at room temperatures usually become very hard and brittle at the temperatures of these liquids and are very easily broken and/or shattered.

3.2 Protective Clothing — Eyes should be protected with face shield or safety goggles. Always dry asbestos or dry leather gloves shall be worn when handling anything that is or may have been in contact with liquid. The gloves should be loose fit so that they may be readily removed should any liquid spill or splash into them. It should be remembered that even

TABLE 1 PROPERTIES OF THE ATMOSPHERIC GASES

(*Clause* 2.1)

CHARACTERISTIC	OXYGEN	NITROGEN	ARGON, NEON AND KRYPTON
(1)	(2)	(3)	(4)
Chemical	Oxygen is an active element which, although does not burn, supports combustion and combines, directly or indirectly, with all elements except the rare gases	Nitrogen does not react readily with other elements. It neither burns nor supports combustion. It combines with some of the more active metals, such as calcium, sodium and magnesium, to form nitrides	These rare gases are extremely inert. All are monatomic and are distinguished mainly by their different relative weights and atomic structures
Physical	Oxygen is colourless, odourless and tasteless. It is only slightly soluble in water and is a poor conductor of heat and electricity	Nitrogen is colourless, odourless and tasteless. It is only slightly soluble in water and is a poor conductor of heat and electricity	These rare gases are colourless, odourless and tasteless
Colour, odour, etc	Liquid oxygen is pale blue slightly heavier than water, magnetic, nonflammable and does not produce toxic or irritating vapours	Liquid nitrogen is colourless and odourless, slightly lighter than water, nonmagnetic and does not produce toxic or irritating vapours. It is stable against mechanical shock	The characteristics of the liquefied rare gases are similar to those of liquid nitrogen, except as shown in Table 2
Use	Oxygen to be used as a gas is often stored and transported as a liquid for economy and convenience. High-purity liquid oxygen is finding increasing application in laboratory work. It is also used as one of the principal ingredients in rocket and missile propellants	Nitrogen to be used as a gas is often stored and transported as a liquid for economy and convenience. Liquid nitrogen is used for deep refrigeration storage, as a refrigerant in shrink-fitting metal part sand in cold traps, and for various laboratory applications	Liquid neon, which has interesting properties as refrigerant, is an important research tool for such purposes as cooling infrared cells, studies in cryophysics and materials research. Argon to be used as a gas is often stored and transported as a liquid for economy and convenience. The other liquefied rare gases are used in laboratory

TABLE 2 PHYSICAL CONSTANTS OF ATMOSPHERIC GASES AND AIR

(*Clause* 2.1)

CHARACTERISTIC	OXYGEN	NITROGEN	ARGON	NEON	KRYPTON	XENON	AIR
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Molecular weight	32·000	28·016	39·944	20·183	83·80	131·30	28·964
Boiling point, °C	−182·97	−195·80	−185·86	−246·0	−153·4	−108·12	−194·35 to −191·35
Freezing point, °C	−218·80	−210·00	−189·37	−248·6	−157·2	−111·80	—
Density of liquid (normal boiling point), g/cm³	1·139 6	0·808 1	1·392	1·204	2·46	3·063	0·873 9
Density of vapour (normal boiling point), g/l	4·44	4·60	5·707	9·39	8·3	9·7	4·485
Density of gas (NTP*), g/l	1·429 0	1·250 5	1·784	0·899 9	3·745	5·897	1·292 8
Latent heat of vaporization (NB PT), cal/g	50·90	47·58	38·98	21·3	25·8	23·0	49·03
Volume expansion, liquid to gas, at STP†	843·2/1	683·1/1	823·5/1	1 415/1	683·3/1	549·3/1	714·5/1
Percent volume in air	20·95	79·09	0·932 3	0·001 8	0·000 1	0·000 01	—

*NTP = 0°C, 1 atm

†STP = 15·6°C, 1 atm

in gloves one may hold cold equipment only for a short time. It is also advisable to wear overalls or similar type clothing without pockets or turn-ups so that liquid may not be splashed into them. If possible, trousers should be worn outside boots or shoes, particularly gum boots.

3.3 Ventilation — Cryogenic liquids shall be handled in well-ventilated areas to prevent excessive concentrations of gas and hence should not be disposed of in confined areas or places where others may enter. Excessive concentrations of oxygen are a fire hazard. Excessive amounts of the other atmospheric gases in air reduce the concentration of oxygen and may cause asphyxiation.

3.4 Correct Equipment

3.4.1 Containers specifically designed for holding cryogenic liquids should only be used. Such containers are made from materials able to withstand the rapid changes and extreme differences in temperature encountered in working with these liquids. However, even these special containers should be filled as slowly as possible to minimize the thermal shocks which occur when any material is cooled.

3.4.2 Containers designed for low-temperature liquids are built to withstand normal operating pressures. However, all containers should be open or protected by a vent or other safety device which permits the escape of vapours. Where a special vented stopper or venting tube is used, as on some small portable containers, the vent should be checked at regular intervals to be sure that it is not plugged with ice formed from water vapour condensed out of the air. Inadequate venting may result in excessive gas pressure which may damage or burst a container. USE ONLY THE STOPPER SUPPLIED WITH THE CONTAINER.

NOTE — The cloudy vapour that appears when a cryogenic liquid is exposed to air is condensed moisture and not the gas itself. The issuing gas is invisible.

3.4.3 Smaller containers of liquid should never be plugged; cover them when not in use to prevent an accumulation of moisture and plugging of the container outlet with ice. Large storage containers not open to the atmosphere shall be provided with pressure-relieving devices.

3.4.4 Small containers should not generally be stored in the open where they may come in contact with rain or moisture, unless suitable protection from the weather is provided. Even then, excessive moisture on moving parts such as valves, relief devices and couplings might cause malfunction due to external ice formation.

3.5 Correct Identification — Containers should be clearly identified so that only the correct contents may be filled or withdrawn. Mixing liquid oxygen with another liquefied atmospheric gas may be hazardous; in certain instances, the oxygen concentration may increase as time progresses due to

the evaporation of lower boiling point liquids such as nitrogen and argon. Unknown concentrations of oxygen always represent a hazardous condition. If liquid oxygen is introduced into a liquid nitrogen refrigerator, the oxygen may cause any organic material in the refrigerator to burst into flame.

3.6 Correct Transfer Equipment — A filling funnel shall be used whenever liquid is poured into a Dewar flask or other small container. The top of the funnel should be partly covered to reduce splashing. When it is not safe or convenient to tilt the container, a discharge tube shall be used to remove liquid. Discharge tube is inserted through the neck of the container and well down into the liquid until the packing material or stopper on the discharge tube forms a seal in the neck tube of the container. Normal evaporation usually produces adequate pressure for withdrawal. If sustained withdrawal is desired, the container may be pressurized with the gas of liquid product or with an oil-free inert gas. Only pressure just enough to force the liquid out should be used. A discharge tube shall always be used to remove liquid from large 50- or 100-litre containers.

3.7 Installation and Maintenance of Equipment

3.7.1 Equipment or piping for cryogenic liquids shall be installed in consultation with thoroughly experienced persons in low temperature work. The materials used shall be those specifically recommended for use at these extremely low temperatures. Ordinary carbon steel, for example, lose their ductility and become extremely brittle when subjected to the low temperature of any liquefied atmospheric gas. These temperatures also give rise to unique insulation problems and considerations of expansion and contraction.

3.7.2 All of the procedures prescribed by the manufacturer for operating and maintaining equipment used with cryogenic liquids shall always be followed. Everyone who works with these liquids shall be properly trained and supervised by someone with experience in this field.

4. FIRST-AID

4.1 If any of the liquefied atmospheric gases contact the eyes or skin, immediately flood the affected area with large quantities of unheated water and then apply cold compress. If the skin is blistered or if there is any chance that the eyes have been affected, take the patient immediately to a doctor for treatment.

5. SPECIAL PRECAUTIONS FOR HANDLING LIQUID OXYGEN

5.0 The following additional precautions along with the general precautions given under 3 shall be observed in handling liquid oxygen.

5.1 Obtain clearance certificate where it is necessary for work to be carried out involving a flame or arc in which case there is likely to be oxygen enrichment of the surrounding atmosphere.

5.2 Make certain that there is adequate ventilation and circulation of *air* where oxygen cutting, gas welding, brazing or arc welding is required to be carried out in a confined space.

5.3 Make certain that all assemblies and components, including piping, which will be in contact with gaseous or liquid oxygen, are thoroughly degreased and entirely free from oil or grease of any description.

5.4 Only pressure gauges marked 'OXYGEN — USE NO OIL' are to be used for any oxygen service and on no account are these gauges to be used on other services where there is a possibility of the gauge becoming contaminated with oil or any other foreign matter.

5.5 Never use oxygen as a substitute for compressed air or nitrogen.

5.6 Oxygen is not to be used for clearing fumes in a confined space. Such use has caused fatal accidents through the worker's clothing getting ignited.

5.7 No painting is to be carried out around an oxygen plant when the latter is in operation.

5.8 Make certain that all pressure is relieved from the system before attempting to remove any fittings or commencing a repair.

5.9 The liquid should be disposed of by pouring it gently, avoiding splashing on to the ground, which is free from any holes or pockets or preferably in the open, well away from other personnel, naked lights, lighted cigarattes, sparks or any combustible material, such as oil, grease, rags, and so on.

5.10 Fire Hazards

5.10.1 Smoking or open flames or naked light shall not be permitted in any area where liquid oxygen is stored, handled, or where it is loaded or unloaded. Post 'NO SMOKING' signs conspicuously in all such areas and on storage tanks.

5.10.2 Organic material or flammable substance of any kind shall not be permitted to come in contact with liquid oxygen. Some of the materials that can react violently with oxygen under certain conditions of pressure and temperature are oil, grease, asphalt, kerosene, cloth, wood, paint, tar and dirt which may contain oil or grease. Under certain conditions, mixtures of powdered organic materials with liquid oxygen may detonate.

CAUTION: When organic materials, such as those listed in **5.10.2**, are exposed to liquid oxygen, they will burn violently if ignited, even several minutes after they have been in contact with the liquid. Any clothing that has been splashed or soaked with liquid oxygen should be removed immediately and aired away from sources of ignition for at least an hour until it is completely free of oxygen. Any person working with liquid oxygen should ensure that his clothings are aired before approaching any source of ignition.

5.10.3 *Fighting Fires Involving Liquid Oxygen* — Since oxygen itself does not burn, fire is not caused unless combustible material is also present. In any fire involving liquid oxygen, the oxygen plays the same part as oxygen from the air in an ordinary fire. However, the presence of additional oxygen will make any fire burn much faster and more violently. The following fire fighting procedures should be observed:

a) Remove every one not actively engaged in fighting the fire.

b) If possible, shut off the flow of oxygen.

c) Use large quantities of fire extinguishing agent, such as water, preferably in the form of a spray, to cool the burning material below the ignition point. If electrical equipment is involved in the fire, do not use water, use carbon dioxide or dry chemical.

6. SPECIAL PRECAUTIONS FOR HANDLING LIQUID NITROGEN

6.0 The following additional precautions along with those given in **3** shall be observed in handling liquid nitrogen.

6.1 Liquid nitrogen shall be stored and used only in a well-ventilated place. If enough nitrogen gas evaporates from the liquid in an unventilated space, the percentage of oxygen in the air may become dangerously low making anybody present there, unconscious without any warning symptoms, such as dizziness. Remaining in this atmosphere long enough may become fatal. The following first-aid notice shall be hung prominently in the area of handling:

FIRST-AID NOTICE
If a person seems to become dizzy or loses consciousness while working with liquid nitrogen, get him to a well-ventilated area immediately. If breathing has stopped, apply artificial respiration. Whenever a person loses consciousness, summon medical aid immediately.

6.2 Nitrogen build-up is most likely to occur when a room is closed, overnight for example. If there is any doubt about the amount of oxygen in a room, the room shall be ventilated completely before entering it. Waste nitrogen shall not be disposed of in a confined area or a place where someone else may enter.

6.3 Exposure to Atmosphere — Liquid nitrogen is colder than liquid oxygen. Therefore, if it is exposed to the air, oxygen from the air may condense into the liquid nitrogen. If this is allowed to continue for any length of time, the oxygen content of the liquid nitrogen may become appreciable and the liquid will require the same precautions as for handling liquid oxygen. However, most liquid nitrogen containers are entirely closed except for a small neck area and the nitrogen gas issuing from the surface of the liquid forms a barrier which keeps air away from the liquid and prevents oxygen contamination.

6.4 Entering Large Liquid Nitrogen Storage Tanks — Before entering any large liquid nitrogen storage tank, it shall be made sure that all pipes to the tank are blanked or positively closed off. The tank shall then be purged with air. If a check with instruments shows that the atmosphere in the tank is normal air, it shall be safe to enter. Unless all lines are physically isolated, inside atmosphere shall be checked frequently with instruments during work. If, for any reason, the supply of fresh air in the tank is doubtful, breathing apparatus shall be used with its own supply of oxygen or air. Whenever anybody enters a tank, he should make sure that he is equipped with a life line and that an observer is stationed outside to check on his reactions while working. It is a good practice to have the ventilating equipment rapidly changing the air in tanks at all times when personnel are working inside them.

7. SPECIAL PRECAUTIONS FOR HANDLING LIQUID ARGON, NEON AND KRYPTON

7.1 The same special precautions as for handling liquid nitrogen given under **6** shall be followed. To make sure that any of these liquefied rare gases is being used safely, all procedures should be cleared from an experienced and responsible person.

SECTION 2 LIQUID HELIUM

8. GENERAL

8.1 Helium gas is found in air in the ratio of five parts per million. All commercial helium is obtained, however, from natural gas where it exists in concentrations of 0·5 to 2·5 percent by volume, and in rare cases up to 7 percent.

8.2 Helium exists as several isotopes, the most common being helium[4]. The next common isotope, helium[3], is much more rare than helium[4] and is generally unknown outside the research laboratory. Whenever helium is referenced without isotope designation, it may be assumed to be helium[4].

8.3 As a liquid, helium exhibits two highly different characters depending on temperature. Between the boiling point (4·2°K) and the lambda point (2·18°K), it is known as a liquid helium I, and exhibits characteristics typical of other liquids. At 2·18°K the liquid undergoes a transition (the lambda transition) and becomes liquid helium II. This colder liquid exhibits the phenomenon of superfluidity (virtually zero viscosity) and attains an extremely high thermal conductivity — 1 000 times greater than that of copper.

8.4 Among the wide applications for liquid helium are the operation of superconductive solenoids for electronic circuits, masers and lasers; the simulation of outer space temperatures; and the production of ultra-high vacuo by cryogenic means. Unlike the more common cryogenic fluids, the properties of liquid helium are unusual and it requires special equipment and handling techniques.

9. PHYSICAL PROPERTIES OF HELIUM

9.1 The important physical properties of liquid helium are as follows:

a) Molecular weight	4·002 6
b) Boiling point (at 1 atm)C°	– 268·9
c) Freezing point	*See* Note
d) Density of liquid (at boiling point), g/ml	0·125
e) Density of vapour (at boiling point), g/l	16·7
f) Density of gas at (NTP*), g/l	0·1785
g) Latent heat of vaporization (at boiling point), cal/g	4·98
h) Specific heat of liquid (at boiling point), cal/g°C	1·08
j) Specific heat of gas (at NTP*), cal/g °C	1·86
k) Critical temperature, °C	– 267·97
m) Critical pressure, atm	2·27
n) Thermal conductivity of gas (at NTP*), cal cm/cm² sec °C	0·000 34
p) Volume expansion (liquid to gas at NTP*)	700·3 to 1

NOTE — Helium will not solidify at 1 atm. The pressure required for solidification at absolute zero is calculated to be 25 atm. The pressure required for solidification at 4·2°K has been determined experimentally as 140 atm.

*NTP = 1 atm at 0°C

10. GENERAL SAFETY PRECAUTIONS

10.1 The potential hazards in handling liquid helium stem mainly from three important properties, namely:

a) The liquid is extremely cold (helium is the coldest of all cryogenic liquids),

b) Very small amounts of liquid are converted into large volumes of gas, and

c) The ultra-low temperature of liquid helium will condense and solidify air as well as carbon dioxide and moisture.

10.2 Exposure of Liquid Helium to Air and Other Gases — The low temperature of liquid helium will solidify any other gas. If solidified gases and liquids are allowed to form and collect, they may plug pressure relief passages and relief valves. Plugged passages are hazardous because of the continual need to relieve excess pressure produced by heat leaks into continually evaporating liquid. Always store and handle liquid helium under positive pressure or in closed systems to prevent the infiltration and solidification of air or other gases.

10.3 Handling

10.3.1 Always handle liquid helium carefully. At its extremely low temperature, it may produce an effect on the skin similar to a burn. The very cold gas issuing from the liquid may also cause severe burns. Delicate tissues, such as the eyes, may easily be damaged by exposure to these cold gases which is too brief to affect the hands or face.

10.3.2 Any unprotected part of the body shall never come into contact with items of equipment which have only just been removed from contact with liquid helium. The extremely cold surfaces may stick fast and tear the flesh when one attempts to withdraw from it.

10.3.3 In addition to the hazard of burns and of skin sticking to cold materials, objects that are soft and pliable at room temperatures usually become very hard and brittle at liquid helium temperature and are very easily broken and/or shattered.

10.3.4 *First-Aid for Cold Liquid Burns* — If liquid helium contacts the skin or splashes into the eyes, that area should be flooded immediately with large quantities of unheated water and then cold compresses applied. If the skin is blistered or there is any chance that the eyes have been affected, immediate medical treatment shall be obtained. A notice prominently displaying these recommendations should be hung at suitable places.

10.4 Protective Clothing — Eyes shall be protected with face shields or safety goggles. Asbestos or leather gloves shall aways be worn when handling anything that is or may have been in contact with liquid helium. The

gloves should be loosefit so that they may be readily removed in case of accident. Even in gloves one may hold cold equipment only for a short time. It is also advisable to wear overalls or similar type clothing without pockets or turnups so that liquid may not spill or splash into them. If possible, trousers should be worn outside boots or shoes, or in particular gum boots.

10.5 Ventilation — Although helium is non-toxic, it may cause asphyxiation in a confined area without adequate ventilation. Any atmosphere which does not contain enough oxygen for breathing may cause dizziness, unconsciousness, or may be fatal in extreme cases. Helium, being colourless, odourless and tasteless, it is not possibie to detect it by the human senses and will be inhaled normally as if it were air. Liquid containers shall be stored outdoors or in other well-ventilated areas.

10.6 First-Aid for Suffocation — If a person becomes dizzy or loses consciousness when working with liquid helium, he should be removed to a well-ventilated area immediately. If breathing has stopped, artificial respiration shall be applied. Whenever a person loses consciousness, medical aid should be summoned immediately. A notice displaying these recommendations should be prominently hung at suitable locations.

10.7 Oxygen Enrichment Hazards — Atmospheric air will condense on exposed liquid helium-cooled surfaces, such as vaporizers and piping. Nitrogen, having a lower boiling point than oxygen, will evaporate first from condensed air, leaving an oxygen-enriched liquid. To prevent the possible ignition of grease, oil or other combustible materials which could come into contact with the air-condensing surface, such areas shall be cleaned to oxygen-clean standards.

10.8 Adequate Pressure Relief Devices — Most of the cryogenic liquids require considerable heat for evaporation to a gas. Liquid helium, however, needs very little heat for vaporization and consequently evaporates very rapidly when heat is introduced. Rapid and violent expansion will occur if, for example, the container vacuum should fail because air condensing on the inner container surface will add heat quickly to the liquid helium. For this reason pressure-relief devices for liquid helium containers and equipment shall be adequately sized to release the rapidly expanding helium gas safely in case of heat influx through insulation failure or other modes.

11. TRANSFER OF LIQUID HELIUM

11.1 Purging

11.1.1 Purging of cryogenic liquid vessels prior to use is essential to remove any matter considered undesirable to product purity, injurious to equipment functioning or hazardous to personnel. When purging a vessel,

knowledge of the freezing and boiling points of all likely contaminants is important. When liquid helium vessels are involved, it shall be recognized that all other liquids and gases will solidify at liquid helium temperatures. Entrance, therefore, of any gas except pure, dry helium into a helium-cooled vessel will cause formation of solid deposits on internal cold surfaces, thus creating a very hazardous condition.

11.1.2 To purge such contaminants from a vessel at liquid helium temperature, it is necessary to remove any liquid helium present, and warm the vessel to the temperature corresponding to the highest boiling point of any of the contaminants suspected. Therefore, if air has been drawn into the vessel, the vessel shall be warmed to at least −183°C (the boiling point of oxygen) in order to purge the vessel of the air constituent having the highest boiling point. If moist air were drawn into the vessel, it would be necessary to warm the vessel to above the freezing point of water so that the water could be evaporated and the vessel purged with warm dry air or dry nitrogen.

11.1.3 It should be borne in mind that it is not possible to purge a vessel at liquid helium temperature (−269°C) directly with nitrogen, since the purging fluid will immediately freeze upon contact with the helium cold vessel surfaces. However, once a vessel is warmed to above liquid nitrogen temperature, pure nitrogen gas at ambient temperature or above may be used for purging to speed the warming of the vessel. Likewise, if it is possible to utilize pure helium gas economically (such as in a recoverable system), it may be circulated directly through the liquid helium-cold vessel, warming it in one operation to the warmest boiling point temperature of any contaminant.

11.1.4 During purging, the temperature of the vessel may be best approximated at any given time by monitoring the temperature of the existing purge gas, which will normally be close to that of the inner vessel.

11.1.5 If a small vessel contains only pure helium gas, it may be filled directly with liquid helium without concern of contamination. However, if the vessel was first precooled with liquid nitrogen to conserve helium losses during filling, if would require complete removal of all nitrogen by purging the nitrogen-cold container with pure, dry helium gas before being filled with liquid helium.

11.2 Precooling

11.2.1 Depending upon economy, a 'warm' vessel (above liquid nitrogen temperature) may be cooled directly with cold helium gas produced from flash-off of liquid helium, or may be precooled with another cryogenic liquid, preferably liquid nitrogen for safety reasons.

11.2.2 If nitrogen precooling is used, the quantity of liquid nitrogen for cool-down should be no greater in weight than the full liquid helium

capacity of the vessel to prevent over-loading the vessels suspension system. Equipment shall be provided for transferring the liquid nitrogen both into and out of the vessels, since the normal filling and withdrawal procedures for liquid helium containers may not work satisfactorily with the heavier, warmer liquid nitrogen.

11.2.3 Cool-down of transfer lines should always be accomplished wherever possible by trickling liquid helium into the line immediately prior to transfer, thereby making maximum use of the sensible heat of the cold vapour to cool the line. Any attempt to cool the line with large quantities of liquid helium will result in abnormally high evaporation loss from cool-down.

11.2.4 Liquid nitrogen should never be used to precool a flexible helium transfer line; nitrogen is difficult to remove from the convolutions of the flexible line, and will later freeze and cause plugging.

11.3 Withdrawing Liquid Helium

11.3.1 Because of its very low latent heat of vaporization, liquid helium shall always be transferred through well-insulated, vacuum-jacketed lines. Non-vacuum insulation will result in total loss of liquid. The general procedures given in **10.3.1.1** to **10.3.1.7** should be used while withdrawing liquid from any helium container.

11.3.1.1 The transfer line and receiving vessel shall be adequately purged with pure, dry helium gas. Care shall be exercised to purge all joints before assembly of transfer components, and to purge any dead-ended or auxiliary parts of lines which will be helium cooled.

11.3.1.2 When withdrawal dip tubes are used, the dip tube should be inserted into a vessel through a section of rubber hose that may be clamped to the dip tube and container neck (unless other sealing provision is made) to prevent helium leakage about the tube. This is important to prevent loss of transfer pressure and also to avoid condensed air on the exposed portion of the dip tube from running into the vessel during removal of the tube.

11.3.1.3 Pressure for transfer may be provided by normal evaporation pressure buid-up or by addition of pure helium gas from a regulated cylinder. The unusual properties of helium make low pressure transfer preferable. Transfers are generally made at a differential pressure of about 0·07 to 0·14 kg/cm^2 on gauge.

11.3.1.4 To prevent air, carbon dioxide or atmospheric moisture from freezing and causing restrictions in inlet and exhaust lines, a positive pressure shall be maintained at all times in the supplying and receiving vessels. When the ratio of venting falls off, a relief valve or other restriction should be added to retain positive pressure in the helium system.

11.3.1.5 In terminating transfer, the flow of external pressurizing gas (if used) should be immediately stopped so as not to add more warm gas to the supply vessel. The liquid withdrawal line should be immediately removed from open neck-tube type containers, or the liquid withdrawal valve of containers so equipped, immediately closed. Any backflow of vapour through a withdrawal line will bubble up through the liquid and cause unnecessary evaporation of the remaining liquid helium.

11.3.1.6 Where protective caps are provided on transfer connections, they should be replaced immediately after transfer to prevent condensation of moisture on the cold connections.

11.3.1.7 When fill or withdrawal dip-tubes are removed from open neck-tube type helium containers, a closure containing a relief valve should be immediately secured over the opening.

11.4 Filling Small Vessels with Liquid Helium

11.4.0 Rules given in **10.4.1** to **11.4.5** should be observed when filling small vessels.

11.4.1 The vacuum jacketed transfer tube should extend down into the vessel to or below the level at which liquid temperature is finally desired.

11.4.2 Liquid helium should not be impinged on the mass to be cooled. It should be directed toward the bottom of the vessel to prevent excessive boiling and splashing.

11.4.3 Openings into these vessels should be restricted or relief devices added after filling in order to maintain positive pressure in the vessel.

11.4.4 After a small helium vessel has been precooled to liquid nitrogen temperature, it is more efficient to insert the transfer line into the small Dewar after cold helium vapour starts issuing from the transfer line. Otherwise, the expanding warm gas during cool-down of the transfer line may build up too much back pressure in a small Dewar.

11.4.5 After a small helium vessel has been filled, it is essential to remove the transfer line while liquid is still issuing from the line. If the transfer is stopped by reducing the pressure on the supply Dewar, the superheated liquid and gas in the transfer line may flash all the liquid in the small helium vessel before the transfer line is removed.

12. STORAGE OF LIQUID HELIUM

12.0 Two types of containers are in general use for the storage of liquid helium. The first type is designated Duplex Dewars (**11.1**) and the second Gas-Cooled Shielded Dewars (**11.2**).

12.1 Duplex Dewars

12.1.1 In Duplex Dewars, the container comprises four concentric spherical compartments. The inner compartment, containing the liquid helium, is protected from heat inleak by a vacuum jacket contained within a liquid nitrogen compartment which is itself protected by a second vacuum jacket. These four compartments are housed within a steel casing to provide protection during handling. The entire assembly of vessels is supported at the neck of the container.

12.1.2 To minimize the hazards arising from air or other gases solidifying in the neck-tube, a safety adapter may be fitted to the neck of the vessel. A typical arrangement is shown in Fig. 1. This consists essentially of a manifold attached to the top of the Dewar with a tube extending down into the neck. This tube forms a dead pocket of helium gas within the neck tube, which will allow venting should the surrounding annulus become plugged. Relief valves are normally connected via the manifold to the centre tube and surrounding annulus.

12.2 Gas-Cooled Shielded Dewars

12.2.1 In these types of vessels no liquid nitrogen shielding is required. The system usually comprises a central inner liquid helium container, surrounded by one or more radiation shields supported from the neck of the inner vessel. This radiation shield is in thermal contact with the venting gas, and is able to recover most of the available refrigeration as the gas warms to ambient temperature. This shield is contained in an outer vacuum jacket and is usually thermally insulated by means of superinsulation.

12.2.2 Similar safety devices as used on the Duplex type Dewars are also required (*see* **12.1.2**).

13. TRANSPORT OF LIQUID HELIUM

13.1 General — The vessel for transporting shall always be fitted with adequate relief devices. General precautions to be observed for both full and empty vessels are as follows:

a) Container shall be kept vertical.

b) Containers are not to be rolled on a tilted axis (milk churning).

c) Sudden mechanical shocks shall be avoided.

d) Immediately before transport, it should be made sure that the vents are free from blockage and that the relief devices are in working order.

e) If the container is of the type which requires liquid nitrogen shielding, it should be ensured that the liquid nitrogen reservoir is full.

f) It should be ensured that gas is following from the vent immediately after the filled vessels are received and daily thereafter.

g) With containers of the liquid nitrogen jacketed type, liquid nitrogen reservoir is to be topped up daily.

h) Proper filling and transfer tube equipment shall be used.

j) A brass or copper rod shall be kept available for freeing any solid gas blockage. To use, slide the rod gently down to the plugged area, exerting only sufficient force to free the obstruction.

k) Recipients of liquid helium should designate staff familiar with liquid handling techniques to be responsible for ensuring that correct handling procedures are adopted.

m) In any unusual emergency, the liquid helium suppliers shall be contacted immediately.

13.2 Air Transportation

13.2.1 Air transportation of liquid helium requires special safety measures in addition to those required for general shipment.

13.2.2 Liquid helium may only be transported by air when the container is specially equipped for air transportation and satisfies the appropriate legal requirements with regard to safety as well as packaging, labelling and documentation.

13.3 Thermal Oscillations — Because of the unusual properties of helium, the phenomenon of thermal oscillations may at times be observed. These oscillations, recognizable as periodic pressure surges, are caused by a resonant combination of heat transfer and fluid flow effects in tubes leading to an ambient temperature section. They produce added heat transfer into the liquid, consequently additional product loss. To reduce thermal oscillations, tubing leading from the liquid should be vacuum insulated, although this is still not an assurance that oscillations will not occur. Should oscillations occur during transfer, the process should be stopped to prevent total loss of helium. Transfer may be resumed when corrective measures are taken, such as change in position of the transfer tube relative to the warm internal parts of the receiving vessel, or injection of a small amount of warm helium gas into the system. Should oscillations persist, a change in the volume of the receiver by inserting foam glass plugs in the warm space may eliminate them.

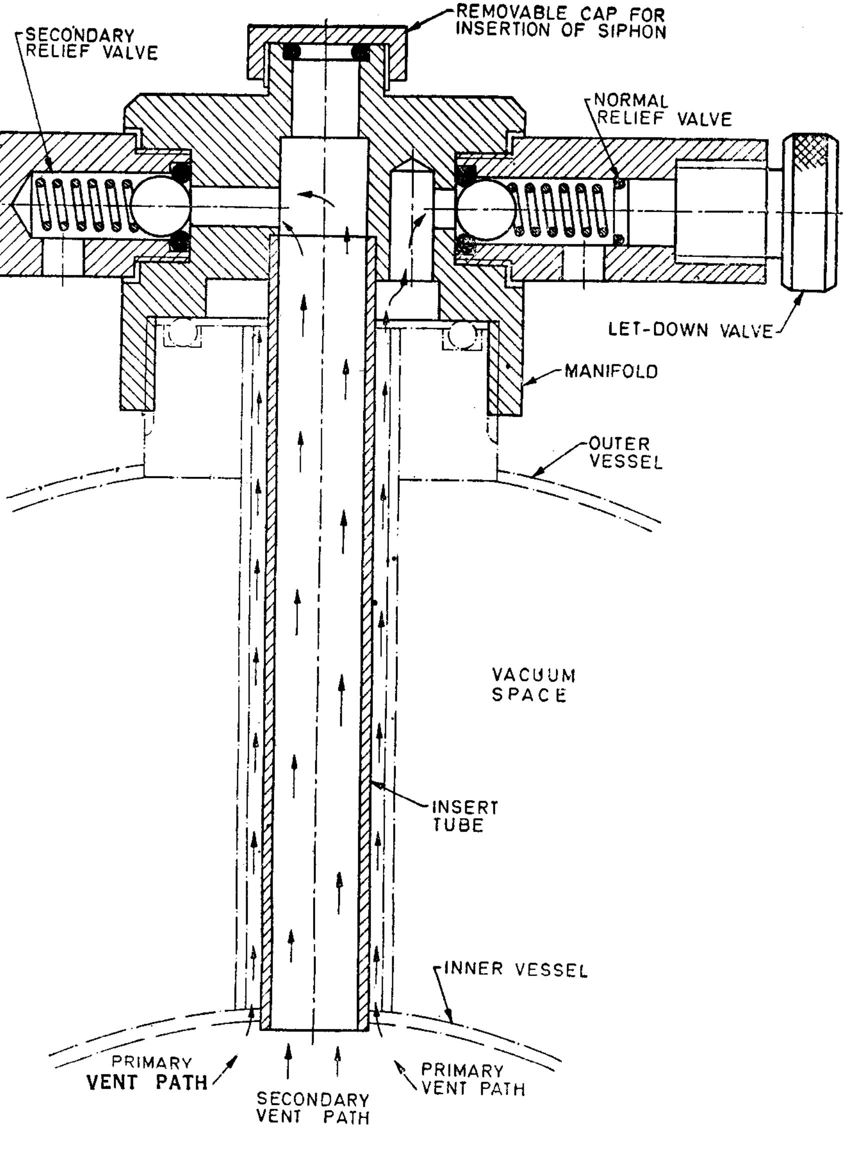

FIG. 1 SAFETY ADAPTER FOR HELIUM VESSEL

SECTION 3 LIQUID HYDROGEN

14. GENERAL

14.1 Although the purpose of the code is to outline the basic techniques for the safe handling of liquid hydrogen, the liquid is invariably accompanied by a certain amount of gas. Since gaseous hydrogen is flammable over a wide range of concentrations in air, much of the material presented in this section has to do with handling the gas safely.

15. PROPERTIES OF LIQUID HYDROGEN

15.1 Some important physical properties of liquid hydrogen are given below:

a) Molecular weight	2·016
b) Boiling point (at 1 atm), °C	−252·9
c) Freezing point, °C	−259·3
d) Density of liquid (at boiling point), g/ml	0·070 81
e) Density of vapour (at boiling point), g/l	1·35
f) Density of gas at NTP*, g/l	0·089 89
g) Latent heat of vaporization (at boiling point), cal/g	108·5
h) Specific heat at NTP*, Cal/g °C	3·411
k) Volume expansion (liquid at boiling point to gas at STP†)	833
j) Critical temperature, °C	−240·2
m) Critical pressure, atm	12·79
n) Flammable limits in air (percent by volume)	Lower 4 Upper 75
p) Flammable limits in oxygen (percent by volume)	Lower 4 Upper 96
q) Ignition temperature (at atmospheric pressure):	
In air, °C	572 approx
In oxygen, °C	560

*NTP = 0°C at 1 atm

†STP = 15·6°C at 1 atm

15.2 Liquid hydrogen has a relatively high coefficient of thermal expansion which should be taken into consideration in the design of equipment for handling liquid.

15.3 The low temperature of liquid hydrogen can solidify any gas except helium.

15.4 Liquid hydrogen is transparent and odourless. It is not corrosive or significantly reactive.

15.5 When liquid hydrogen is spilled on a surface, it tends to cover it completely and, therefore, cools a large area. The evaporation rate of liquid hydrogen greatly reduces the period during which a spill constitutes a potential fire hazard. However, with a large spillage the surface freezes and the air above the surface liquefies. A large cloud of the very cold gas caused by evaporation of liquid on the surface stays over the surface till it picks up heat to rise up. If this gas gets ignited, it burns smoothly in air. The visible cloud does not confine to the flammable zone and ignition is possible outside the clouds. If 7·8 litres of liquid hydrogen are spilled on 50 cm below an open flame, the mixture is ignited almost immediately, after about 1/2 second the flame reaches the height of nearly 8·5 metres with a maximum width of 6 metres.

15.6 The duration of burning of liquid hydrogen after a small spill is usually very brief, lasting only a few seconds. In larger spills on hydrogen burning from open vessels, combustion may take several minutes until all the liquid is evaporated. The flame temperature is about 1900°K, but the radiation intensity is low. Therefore, it is possible to get close to small quantities of smoothly burning liquid hydrogen because the flame has little luminosity and low radiant intensity. One is also able to approach flames more closely for fire fighting or closing for supply valves.

15.7 Liquid hydrogen mixed with solid air does not readily produce an explosive mixture unless fired by a detonator or high energy spark. Considerable enrichment with air is usually required and the efficiency of explosion is much less than a corresponding gaseous explosion.

15.8 Natural hydrogen of atomic weight 1·008 is a mixture of two stable isotopes; hydrogen of atomic mass 1; and deuterium of mass 2. Ordinary hydrogen is a mixture of H_2 and HD molecules in the ratio 3 200 to 1.

15.9 Different relative orientations of the two nuclear spins in the diatomic molecules H_2 and D_2 give rise to the molecular modifications designated by the prefixes ortho and para. The high temperature equilibrium concentration of hydrogen, closely approached at room temperatures and known as ' normal ' hydrogen, is 75 percent orthohydrogen (nuclear spins in the same direction) and 25 percent parahydrogen (nuclear spins in the opposite direction). At the boiling point of liquid hydrogen, 20·4°K, the equilibrium ortho and para concentrations are 0·21 and 99·79 percent respectively. The high temperature equilibrium composition of deuterium

is two-third ortho and one-third para, while at 20·4°K it is about 98 percent orthodeuterium.

15.10 Hydrogen is the lightest of all elements and diffuses rapidly through porous materials and through some metals at red heat. The thermal conductivity of hydrogen gas at atmospheric temperature and pressure is about seven times greater than for air. Hydrogen is a flammable gas. It burns in air with a blue, almost invisible flame.

15.11 Hydrogen is flammable over a wide range of compositions when mixed with air. Mixtures containing 4 to 75 percent hydrogen in air be ignited readily. One may consider hydrogen/air in its most incendiary composition (27 to 30 percent hydrogen in air) at normal temperature and pressure and allow a safety margin when approaching the limits of flammability.

15.12 Inside these limits, mixtures of hydrogen/air (17 percent to 60 percent hydrogen) detonate when ignited by a sufficiently powerful ignition source. Powerful shockwaves are provided and the pressure may rise about 20 fold. In some cases, shockwaves are reflected, with the result a brief pressure pulse of 40 times the initial pressure is obtained. Weaker mixtures may also produce detonation when a combustion front moving at about 2·5 metres/sec compresses the ambient gas ahead by volume expansion. One may reach a condition in which a detonation may be propagated after precompression to *n* atmospheres and a pressure pulse of 40 *n* atm could develop. Such conditions should only be met in long pipework or in large enclosed volumes and is the most severe aspect. Usually hydrogen/air mixtures burn without detonation because mixture and initiation source are generally weak or there is insufficient mixing.

15.13 Hydrogen is non-toxic but may cause asphyxiation by exclusion of air in confined areas.

16. GENERAL SAFETY PRECAUTIONS

16.1 The potential hazards in handling liquid hydrogen stem mainly from three important properties.

a) the liquid is extremely cold,

b) very small amounts of liquid are converted into large amount of gas, and

c) the issuing gas is highly inflammable.

16.1.1 Also three chief dangers which exist with liquid hydrogen are contamination by oxidants, leaks and spills.

16.1.2 In order to avoid contamination with air, all hydrogen plants and vessels should be invariably kept at above atmospheric pressure. Leaks

are then always outwards and can normally be detected by the cloud of vapour and ice crystals surrounding them, although detection is more difficult if they have become ignited, since hydrogen flame is invisible in daylight.

16.2 Protective Clothing — Same as in **10**.

16.2.1 *First-Aid* — The following first-aid notice for cold liquid burns should be hung at prominent places:

> FIRST-AID NOTICE
>
> For Cold-Liquid Burns
>
> If liquid hydrogen contacts the skin or eyes, immediately flood that area with large quantities of unheated water and then apply cold compresses. If the skin is blistered or there is any chance that the eyes have been affected obtain immediate medical treatment.

16.3 Ventilation — Always store and handle hydrogen in well-ventilated rooms to prevent accumulation of flammable concentrations. Hydrogen gas evolving from the liquid may reduce the oxygen content below 16 percent by volume to cause asphyxiation of personnel. A person may become unconscious without sensing any warning symptoms such as dizziness. It should be noted that lower flammable limit of hydrogen in air will be reached well before this condition is achieved. If there is any doubt about hydrogen concentration in an unventilated room, ventilate the room completely before entering it.

16.3.1 The following first-aid notice should be hung prominently at suitable locations:

> FIRST-AID NOTICE
>
> For Cold Gas Exposure
>
> If a person becomes dizzy or loses consciousness while working with liquid hydrogen, get him to a well-ventilated area. If breathing has stopped, apply artificial respiration. Whenever a person loses consciousness, summon medical aid immediately. Keep all sources of ignition away from the overcome person.

17. PRECAUTIONS IN HANDLING AREA

17.1 Safety precautions to be observed in areas where hydrogen is handled is briefly given in **17.1.1** to **17.1.5**.

17.1.1 Efficient ventilation should be ensured to permit rapid diffusion of hydrogen gas.

17.1.2 Open flame or smoking shall not be permitted in the area.

17.1.3 Non-flameproof electrical equipment shall be placed in a safe area.

17.1.4 All electrical equipment located in the area should be of the type, approved by the Chief Inspector of Explosives in India (approved type for this purpose is Group IV, *see* IS : 2148-1968*).

17.1.5 Personnel entry in the area shall be restricted and the area barricaded to limit access. There shall be automatic monitors to signal dangerous proportions of hydrogen in the air.

17.2 Safety precautions to be observed while working with the equipment that deals with hydrogen is briefly given in **17.2.1** to **17.2.6**.

17.2.1 All vessels and pipes should be purged before introducing liquid hydrogen.

17.2.2 Equipment should be tested for hydrogen leaks on ingress of air into it during its working.

17.2.3 Filling and refilling operations of liquid hydrogen containers should be carefully done and it should be ensured that the containers are free from air by flushing them with liquid nitrogen or other liquid gas.

17.2.4 Dewar weights should be manageable to be handled by a single man and the Dewars should be properly designed for venting, insulation and handling.

17.2.5 Sealing liquid hydrogen containers with adhesive tapes should not be allowed. This is a source of static sparks and this causes explosions.

17.2.6 Persons working with liquid hydrogen should wear goggles and gloves. Liquid hydrogen in contact with skin gives serious burns; contact of bare hands with piping or containers is hazardous and should be avoided.

17.3 The precautions given in **17.3.1** to **17.3.5** shall be taken to control static charges.

---

*Specification for flameproof enclosures of electrical apparatus (*first revision*).

17.3.1 All metal parts of equipment and piping, which contain hydrogen, should be grounded.

17.3.2 Anti-static belts for machinery in the place of ordinary ones, which are not spark-free should be used.

17.3.3 Nylons or other synthetic clothing should be avoided in areas where hydrogen is handled. Combing of hair also should be avoided.

17.3.4 All personnel should be grounded before they handle Dewars. They should wear conducting shoes.

17.3.5 Spark-proof (brass) tools should be used although they do not necessarily give adequate safety against ignition as the energy of activation is small.

18. FIRE PREVENTION

18.1 To prevent fire incidents with hydrogen, the main principles to be applied are as follows:

a) Segregation, by keeping hydrogen and air separate;

b) Ventilation, sweeping away hydrogen which may have leaked out; and

c) Ignition control, removing potential sources of ignition.

18.2 In the working area, the allocation of space should be generous, preferably with a high sloping roof or ceiling, allowing free escape for the light buoyant hydrogen at the highest point. One may rely on the natural draught principle by using doors with levers at the bottom and an open roof ridge. During warm weather the open doors and windows increase ventilation, whereas in extreme winter judiciously spaced steam radiators provide upward convection to assist the buoyancy flow of contaminated air (detectors have shown that lateral diffusion of hydrogen is not so marked in a sudden spill of a few litres of liquid). Hydrogen rises in a compact area to clear the building within a few seconds.

18.3 The following formula may be applied to determine the percentage of hydrogen in the atmosphere when V_1 litres of liquid hydrogen are spilled in an unventilated room:

$$\text{Percentage hydrogen} = 90\,560 \frac{V_1}{V}$$

where

V = Volume of unventilated room in litres.

18.3.1 It is, therefore, advantageous to work in a large room, for instance, a spill of 5 litres of liquid hydrogen in a room $6 \times 6 \times 6\ m^3$ is unlikely to cause an explosion even in the absence of any ventilation. A good way of removing contaminated air is to work the liquid hydrogen equipment under a hood leading into a separate vent stack particularly for smaller operation. The vent should not be shared with non-hydrogen users and an extractor is not recommended. Where it is important to increase the draught, this may be induced by blowing fresh air into the stack. It is preferable to blow fresh air into the working area rather than extract it by way of an electric fan, since electrostatic discharges on blades may cause ignition. Ventilation rates of 20 to 30 air changes are recommended.

18.4 Control of Ignition — All potential sources of ignition should be controlled and no naked lights or flames be allowed where hydrogen is handled. Attention should be given to electrical devices because they are most likely to cause sparks or hot spots as a result of failure or overloading. Electricals should be in flameproof enclosures (*see* Group IV of IS : 2148-1968*) which should be sufficiently strong to withstand any explosion of the prescribed gas and to prevent transmission of the flame to surrounding flammable gas. Ignition of surrounding gas is possible across joints and flanges unless the gap is sufficiently close and the flame path is long.

19. LIQUID HYDROGEN CONTAINERS AND STORAGE

19.1 It is desirable to convert liquid hydrogen to the stable paraform during liquefaction to avoid product loss during storage. It is usual to allow the evaporated gas to escape freely and in such a way that air is not permitted to diffuse back into the container. It is essential to keep the mouth of Dewars connected to a suitable vent line and to use a simple non-return Bunsen valve. In laboratories a tight wad of cotton wool is usually pushed into the mouth of the neck-tube. It is also necessary to check daily whether the neck-tube is clear by carefully lowering a stout copper tube fitted with a collar. This relatively warm metal tube will usually vaporize solid air obstructions and the collar will prevent the tube from slipping too far into the Dewar and damaging the bottom. Alternatively, the obstruction may be dispersed by means of a jet of warm hydrogen introduced by means of a suitable tube.

19.2 Superinsulated vessels carry separate liquid and vent lines, which may be valved off. The vent is fitted with a relief valve and bursting disc and gives adequate protection for almost any event.

*Specification for flameproof enclosures of electrical apparatus (*first revision*).

19.3 It is recommended that liquid hydrogen containers should be stored out of doors when not in service and smaller vessels should be protected from the weather. All vessels should be connected to a vent pipe which discharges hydrogen at a high point away from ignition sources. A flame trap or water seal may be employed at the discharge point.

19.4 Storage of liquid hydrogen containers shall be away from the liquefaction plant. The production and storage shall be planned according to the experimental programme; excessive storage is uneconomic and hazardous.

19.5 The storage area shall be protected from any source of fire or ignition. There shall not be any combustible matter in the area.

20. PURGING AND TRANSFER OF LIQUID HYDROGEN

20.1 Purging — Purging of hydrogen systems is required to avoid:

a) combustible mixtures within the system;

b) contamination of hydrogen; and

c) build-up of gases which freeze into particles, and during dismantling.

20.1.1 Purging by vacuum is feasible provided the system stands vacuum and does not allow for leaks at joints or other places. Purging is preferred with inert fluids, namely, liquid nitrogen or liquid helium where available. Water provides a convenient means to purge vent lines containing hydrogen. The following procedure shall be followed to prepare a system to receive liquid hydrogen:

a) Evacuate system to 1 cm of Hg;

b) Introduce liquid nitrogen without admitting air;

c) Allow nitrogen to cool and drain off excess liquid nitrogen;

d) Remove nitrogen by evacuation to 1 cm of Hg;

e) Allow hydrogen to purge out residual nitrogen. Continue to build a positive pressure; and

f) Allow liquid hydrogen in the system.

20.2 Transfer — Liquid hydrogen is transferred from storage containers into receivers by means of vacuum jacket. It is so arranged that the heat of conduction between the inner tube and the outer jacket is low and the vacuum substantially limits the convection loss. Radiation losses are not usually prevented, as the duration of most transfers is short. For longer

periods superinsulated lines may be used, with the inner tube protected by a wrapping consisting of layers of reflecting surfaces separated by thermal insulation.

20.2.1 Transfer lines, or siphons as they are often called, may be made in any size but usually they are related to the quantity, rate and frequency of the liquid hydrogen transferred. There is no difficulty about inserting a valve, cock or flexible element into such a line, provided the heat mass and the subsequent heat conduction losses are acceptable. Transfer tubes may be joined or fitted by means of male/female couplings employing a neoprene 0-ring seal.

20.2.2 In general, for small scale transfers liquid hydrogen is transferred by exerting a sufficient pressure above the liquid either by introducing hydrogen gas from an outside source such as a gas cylinder or by evaporating some of the liquid gradually or through a built-in evaporator (pressure raising device). For large scale transfers, it may be convenient to employ a submerged pump to give nearly instant delivery of liquid at selected flow. It is important to earth all units carrying hydrogen.

20.2.3 Before dismantling a vessel which may contain liquid hydrogen, the liquid should be removed first, if necessary, by blowing warm hydrogen into the vessel. This is followed by evacuation and breaking the vacuum with nitrogen, argon or helium.

21. TRANSPORT

21.1 The transport of Dewars has associated hazards during filling or transferring of liquid hydrogen from them into the equipment, due to leaks or by trapping of moisture. Overflows shall also be avoided by use of suitable devices. All the associated gadgets shall be flushed with liquid nitrogen and checked for absence of oxygen in the system.

21.2 The transport of even 200 ml of liquid hydrogen from small units requires careful planning if the material passes through the crowded streets. The transport van shall be designed to have explosion proof sides, and suited for the purpose with due regard to fire and explosions risks, static charge and hydrogen gas leakage. The container Dewar shall be thoroughly insulated and checked for leakage before transport.

21.3 The van shall not pass through the streets without escort preceding and following it at the safe distance showing up the danger signals (red flags). The transportation shall be done in accordance with the existing rules, if any, governing transport of liquid hydrogen. Liquid hydrogen shall be not transported during the crowded hours of the day.

22. VENTING AND DISPOSAL

22.1 The venting of spent hydrogen is associated with hazard and shall be done very carefully.

22.2 In using 200 ml of liquid hydrogen, the vent gases (about 360 000 ml at room temperature pressure) shall be released gradually in a naturally ventilated atmosphere through a long vent tube over the roof. The explosion hazards are absent if the release is very gradual and no sources of ignition are present near release point.

22.3 Disposal of vent gases by burning is a safer practice provided the amounts released are large and continuous, and there is an adequate safety in vent construction and water seal. The water vent tank is used to stop flashbacks which might occur if the hydrogen flow is below velocity and air diffuses down the pipe and mixes with the hydrogen gas.

22.4 An alternative vent design is to omit the water seal tank and introduce the natural gas into the safety vent at a point near the vacuum tank so that the gas flows through the whole vent line and purges it.

22.5 The actual vent design shall be made on the basis of available gas for disposal and location. The vent line design shall consider the dependence of lower limits of flammability on the size of vent piping.

23. LEAK DETECTION SYSTEMS

23.1 Manually carried or portable detection systems are not considered advisable from personnel safety considerations in large production programmes. It is necessary to install suitable sensors at various places for remote detection. For small laboratories portable detectors shall be used that are sensitive to 20 percent of lower explosive limit (about 1 percent hydrogen).

24. FIRE FIGHTING

24.1 Although specific fire fighting procedures depend upon the quantity of liquid hydrogen involved, the following general procedures are applicable to all fires involving hydrogen:

a) Remove everyone not actively engaged in fighting the fire. Liquid hydrogen exposed to the atmosphere will produce a cloud of moisture condensed from the air. The flammable-mixture zone may extend beyond this vapour cloud and, therefore, personnel should be evacuated to points well outside the area of visible moisture.

b) If at all possible, shut off the flow of liquid or gaseous hydrogen.

c) Use large quantities of water, preferably in the form of a spray, to cool adjacent exposures and to cool any burning material below the ignition point. Adequate sprinkler systems and fire hoses with stream-to-spray nozzles should be considered for areas where large quantities of liquid-hydrogen are handled.

d) Depending upon the circumstances it is not usually advisable to extinguish a hydrogen flame in confined areas if it is not possible to shut off the hydrogen supply. The continued escape of unburned hydrogen may create an explosive mixture which may be ignited by other burning material or hot surfaces. Usually it is better to allow the hydrogen to burn in confined areas and keep adjacent objects cool with water rather than risk the possibility of an explosion.

e) If electrical equipment is involved in the fire, be sure the electrical supply is disconnected before using water for fire fighting or use carbon dioxide or dry chemical extinguishers.

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